

Sentinel-1 Toolbox

DEM generation with Sentinel-1 Workflow and challenges

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Interferometry Tutorial

The goal of this tutorial is to provide novice and experienced remote sensing users with step-by-step instructions on interferometric processing with Sentinel-1 IW products for DEM generation.

Background

What is Interferometry?

Interferometric synthetic aperture radar (InSAR) exploits the phase difference between two complex SAR images taken from slightly different sensor positions and extracts information about the earth's surface.

A SAR signal contains amplitude and phase information. The amplitude is the strength of the radar response and the phase is the fraction of one complete sine wave cycle (a single SAR wavelength). It is primarily determined by the distance between the satellite antenna and the ground targets.

By combining the phase of two images after coregistration, an interferogram can be generated whose information is highly correlated to topography. However, there are many other contributions to the interferogram which potentially decrease the quality of the resulting elevation product, such as atmospheric disturbances, unwrapping errors and decorrelation due to surface changes.

Further reading: [InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation](#)

To cite this tutorial, and for a comprehensive introduction to the generation of digital elevation models with Sentinel-1 please refer to this review paper:

- Braun, A. (2021): Retrieval of digital elevation models from Sentinel-1 radar data – open applications, techniques, and limitations. *Open Geosciences*, 13(1), 532-569. [doi:10.1515/geo-2020-0246](https://doi.org/10.1515/geo-2020-0246)

Sentinel-1 Interferometric Wide Swath Products

The Interferometric Wide (IW) swath mode is the main acquisition mode over land for Sentinel-1. It acquires data with a 250 km swath at 5 m by 20 m spatial resolution (single look). IW mode captures three sub-swaths using Terrain Observation with Progressive Scans SAR (TOPSAR). With the TOPSAR technique, in addition to steering the beam in range as in ScanSAR, the beam is also electronically steered from backward to forward in the azimuth direction for each burst, avoiding scalloping and resulting in homogeneous image quality throughout the swath.

TOPSAR mode replaces the conventional ScanSAR mode, achieving the same coverage and resolution as ScanSAR, but with a nearly uniform SNR (Signal-to-Noise Ratio) and DTAR (Distributed Target Ambiguity Ratio).

IW SLC products consist of three sub-swaths (Figure 1, red labels) image per polarization channel, for a total of three (single polarizations) or six (dual polarization) images in an IW product. Each sub-swath image consists of a series of bursts (Figure 1, white labels), where each burst has been processed as a separate SLC image. The individually focused complex burst images are included, in azimuth-time order, into a single sub-swath image with black-fill demarcation in between, similar to ENVISAT ASAR Wide ScanSAR SLC products.

More information on Sentinel-1 IW products is provided here: <https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/acquisition-modes/interferometric-wide-swath>.

The data used in this tutorial lies in eastern Turkey and includes the city of Erzincan and its surrounding landscapes. Figure 2 shows the extent of the Sentinel-1 data (red) and of the subset used in this tutorial (blue).

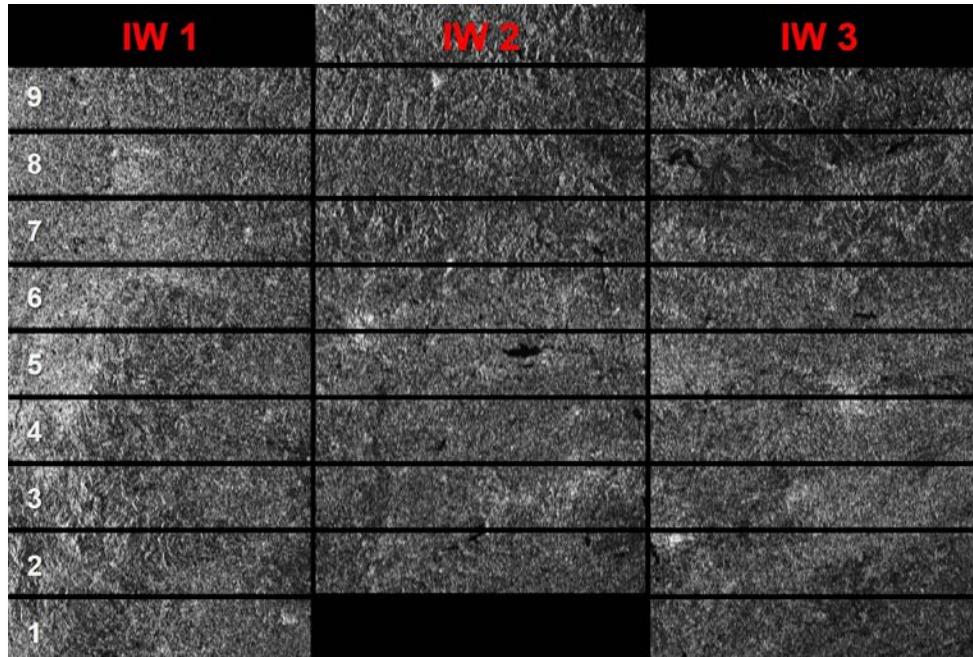


Figure 1: Sub-swaths (red) and bursts (white) of S1 IW products

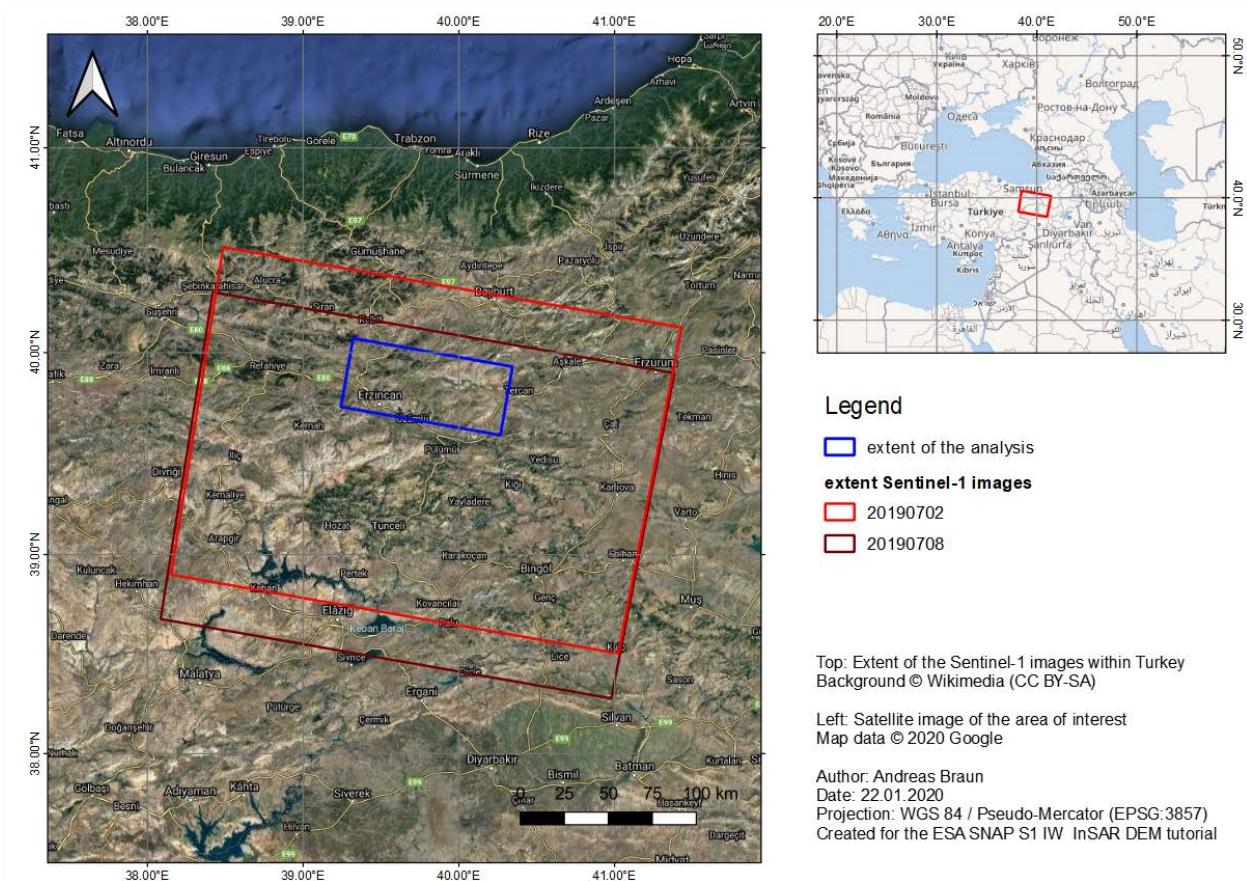


Figure 2: Extent and location of the data

Preparation

Selection of suitable images

A crucial step for a successful DEM generation is the selection of an image pair with suitable properties. Among others, favorable conditions include:

- Short **temporal baseline**: The time between the first and the second image should be kept as short as possible to reduce the risk of temporal decorrelation of the phase. Whenever surfaces change between the first and the second acquisition, the signal will be out-of-phase and no longer exploitable (Figure 3, right). This happens over vegetation and water areas, but also under changing moisture conditions, moving objects etc. Especially C-band radar (Sentinel-1) is prone to temporal decorrelation because of the comparable short wavelength. Smaller areas of decorrelations are tolerable but large parts of the image should produce an interferogram with clearly visible fringes and high coherence (see chapter "Interferogram Formation and Coherence Estimation"). **Accordingly, generating DEMs from Sentinel-1 over vegetation areas will result in bad quality.** If you have strong seasonality, try to find image pairs at times of minimum vegetation cover.
- Suitable **perpendicular baseline**: The distance between the satellites' positions at the time of image acquisition should be between 150 and 300 meters ([ESA TM-19B](#), chapter 1.4). This grants an angle between both acquisitions which allows to retrieve topographic variations from parallax-like effects: targets of different heights are displaced relative to each other in the two images based on their altitude ([Rosen et al. 2000](#)). If the perpendicular is too small, these topographic effects on the differential phase are not pronounced enough. With too large baselines, the coherent phase is increasingly different, also leading to decorrelation.

The Sentinel-1 mission was mainly designed for the retrieval of deformations (DInSAR) and not for DEM generation ([Geudtner et al. 2016](#)). Most of the baselines between two consecutive images are below 30 meters. **Image pairs with short temporal baselines and large perpendicular baselines can be hard to find.**

A helpful tool to identify the baseline of two images and to find suitable image pairs is provided by the Alaska Satellite Facility: [ASF Baseline tool](#)

- Suitable **atmospheric conditions**: Water vapor in the atmosphere causes phase delays and potentially decreases the quality of the measurement. It is therefore advisable to select images acquired during dry periods and to make sure that no rainfall occurred during both image acquisitions.

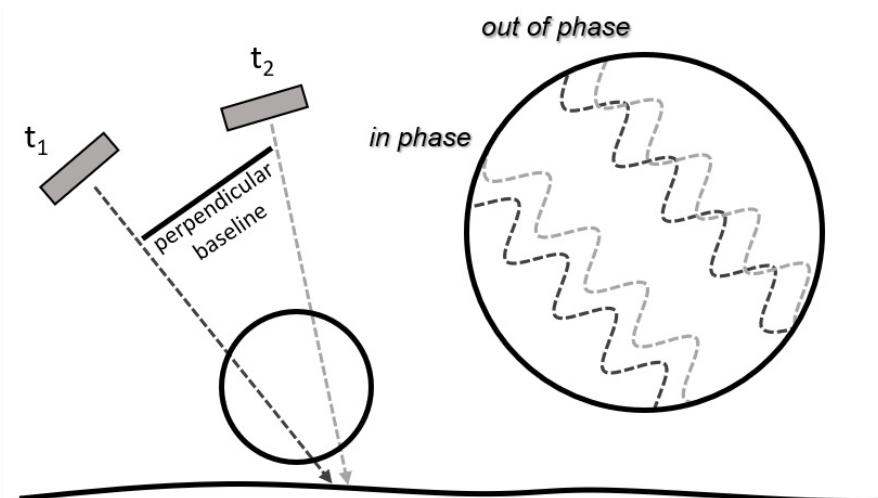


Figure 3: Image geometry and phase decorrelation ([Braun 2019](#))

Download the Data

The data used in this tutorial can be downloaded from the Copernicus Open Access Hub at: <https://scihub.copernicus.eu/dhus> (login required, registration is free)

Search for the two product IDs and download them:

S1B_IW_SLC_1SDV_20190702T032447_20190702T032514_016949_01FE47_69C5

S1A_IW_SLC_1SDV_20190708T032532_20190708T032559_028020_032A14_33CA

As some of the required steps are computationally intensive, it is good to store the data at a location which offers good reading and writing speed. If your computer has an internal SSD, processing should be done there to ensure best performance. Network drives or external storage devices are not recommended. Also, paths which include special characters should be avoided. In this tutorial, the data is stored under C:\Temp\S1_InSAR_DEM\.

Install snaphu

This tutorial can entirely be done within SNAP. Yet, as an external software package, *saphu* (statistical-cost network-flow algorithm for phase unwrapping) has to be installed separately. For more information on this tool, please visit <https://web.stanford.edu/group/radar/softwareandlinks/sw/saphu/>.

To install the plugin in SNAP, go to *Plugins* (under the *Tools* menu, Figure 4) and search for “SNAPHU Unwrapping” in the *Available Plugins* tab. Select it and click **Install**.

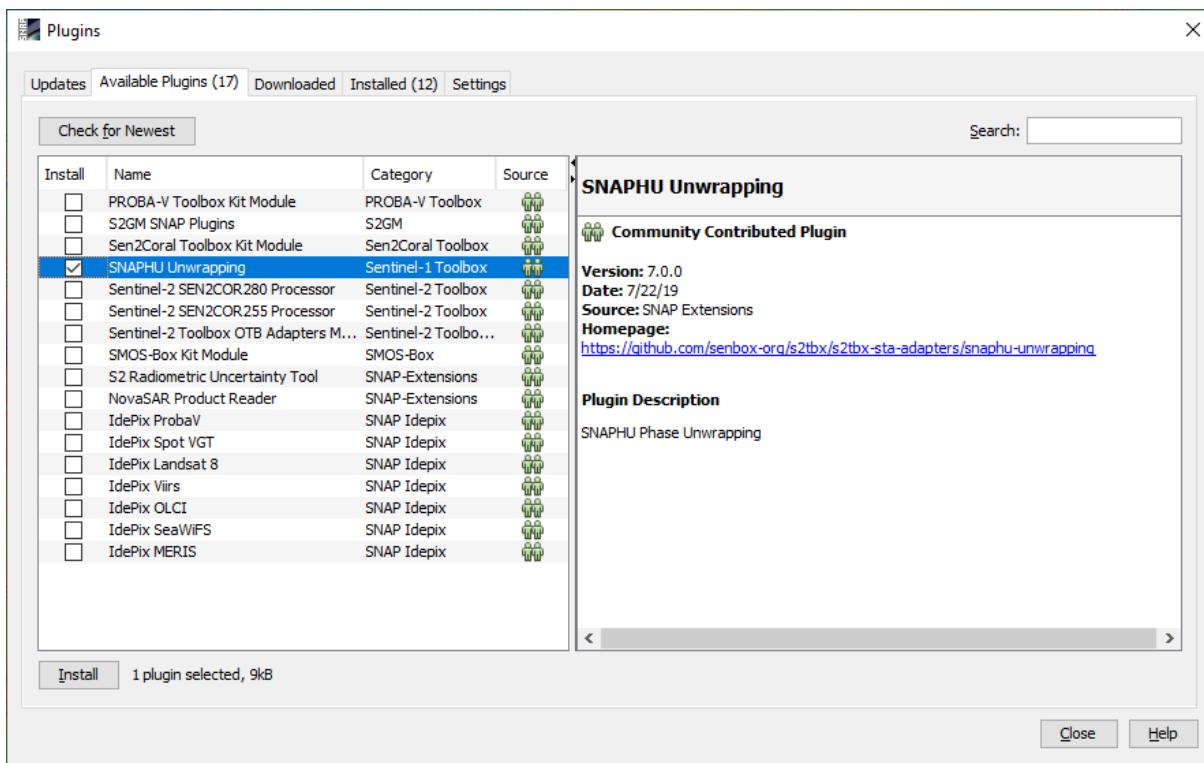


Figure 4: The Plugins interface

You will be asked to proceed with “Next” and restart SNAP (Figure 5). This creates a menu entry for *saphu* unwrapping in the Interferometry menu.

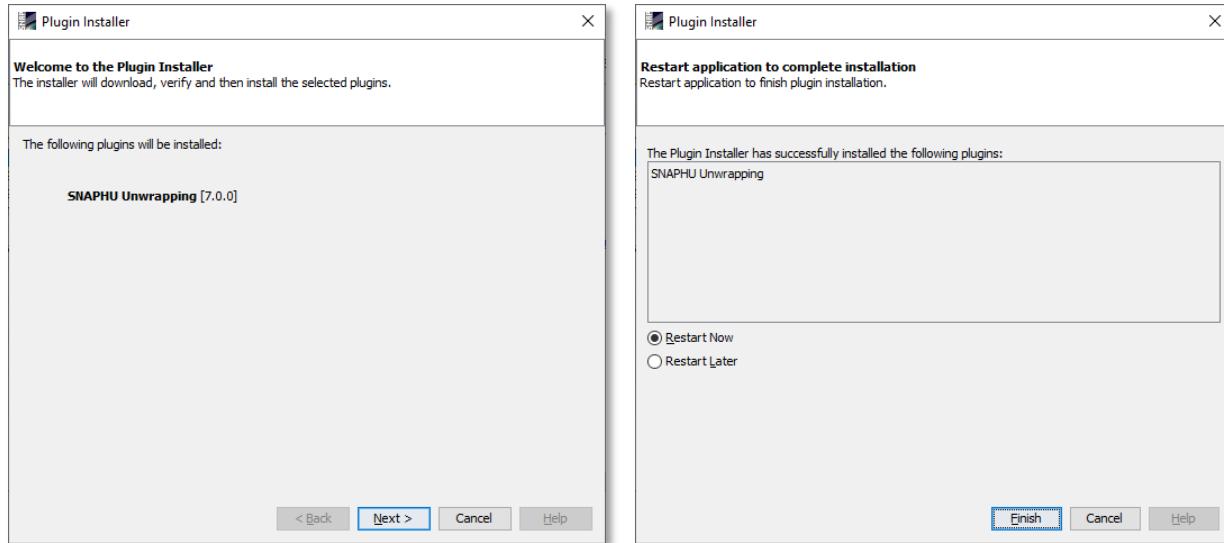


Figure 5: Installation of the snaphu plugin

After you have restarted SNAP, you need to install the snaphu bundles as well. Go to *Manage External Tools* in the *Tools* menu. Select “Snaphu-unwrapping” and click **Edit the selected operator** to open the configuration (Figure 6). Select a suitable Target Folder (here C:\GIS) where snaphu will be installed and proceed with **Download and Install Now**. You will then get a confirmation “Bundle was installed in location C:\GIS\snaphu-v1.4.2_win64” (this may differ according to version, path and operating system).

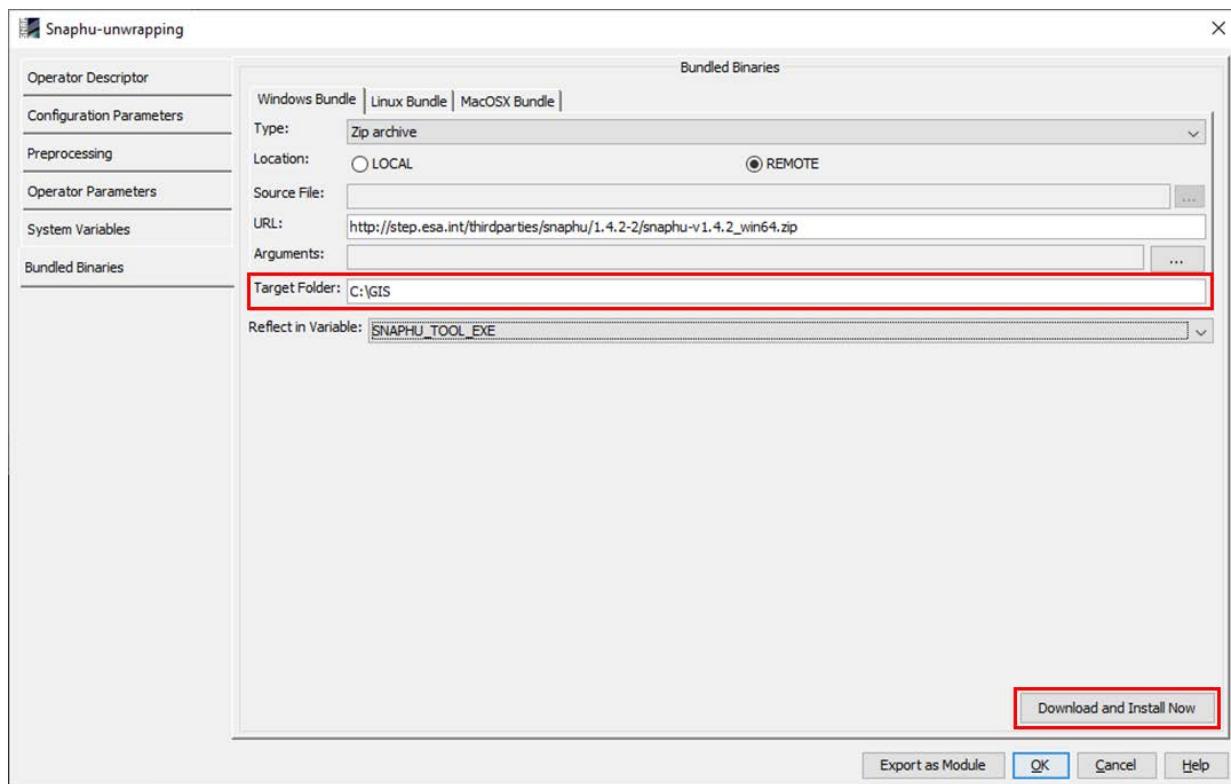


Figure 6: Installation of the snaphu bundles

Open the Products

Use the  **Open Product** button in the top toolbar and browse for the location of the downloaded data. Select the two zip files and press **Open Product**.

In the *Products View* you will see the opened products. Each Sentinel-1 product consists of Metadata, Vector Data, Tie-Point Grids, Quicklooks and Bands (which contains the actual raster data, organized by polarization and sub-swath as demonstrated in Figure 1).

As the data is still compressed in the zip file and each sub-swath covers a large area, it is not advised to open the bands in their current state, because it takes a considerable time until SNAP loads the raster. If you still want to check the data before proceeding double-click on the **Intensity_IW1_VV** band to view the raster data.

Another way to identify the location of your study area within the product (required for the next step), you can use the *World View* or *World Map* (to see its full extent on a base map) or open the *Quicklook* for a preview of the dataset in an RGB color representation.

Note: If you miss any items in your user interface you can activate them in the menu under *View* and *Tool Windows*.

The *World View* or *World Map* menus are also a good way to check if your image belong to the same relative orbit (required for interferometry) and if they are shifted along-track, as it is the case here. It is not a problem for interferometry but needs to be taken into account in the next step (TOPS Split).

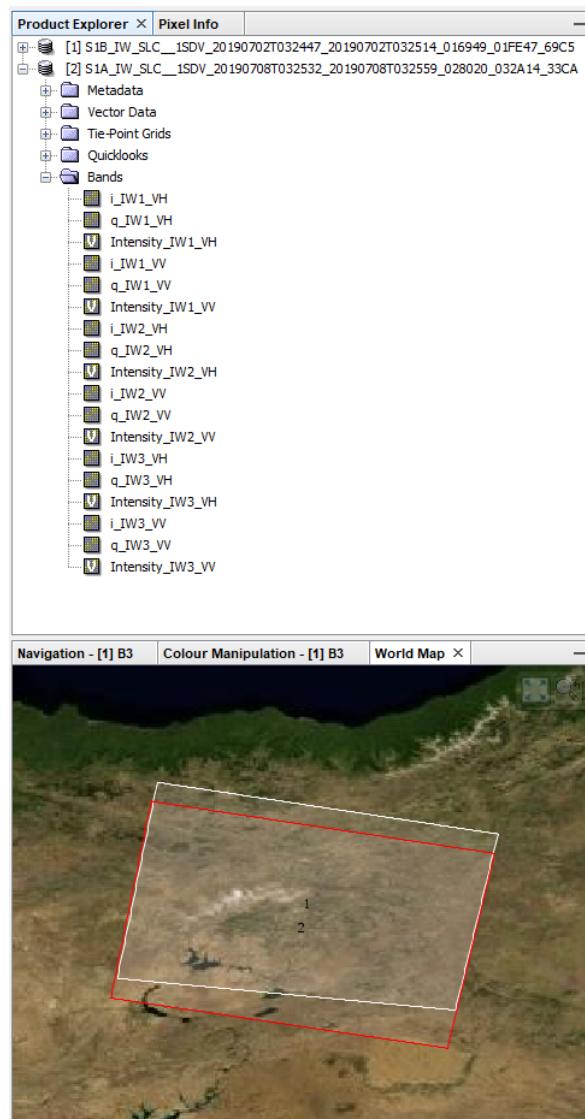


Figure 7: Product Explorer and World Map

Check baseline information

As already indicated in the introduction, the quality which can be expected from DEM generation strongly depends on the properties of the two images, most importantly the position of the satellites at the time of acquisition. Their relative distance is called the **perpendicular baseline** (Figure 3). The larger this difference, the more details will be contained in the computed interferogram with respect to elevation changes. As shown in Figure 8, a perpendicular baseline of 151 meters will result in a higher density of fringe patterns and therefore be more suitable to describe terrain changes than baselines of 67 m or 27 m.

The time between the first and the second image is called the **temporal baseline**. The shorter this period (at best 6 or 12 days for Sentinel-1) the lower is the loss of interferogram quality due to phase decorrelation, especially over natural surfaces. As shown in Figure 9, longer temporal baselines lead to bad interferogram quality. At these areas, no reliable height information cannot be extracted. If these areas become too dominant in the interferogram, no DEM can be extracted in general.

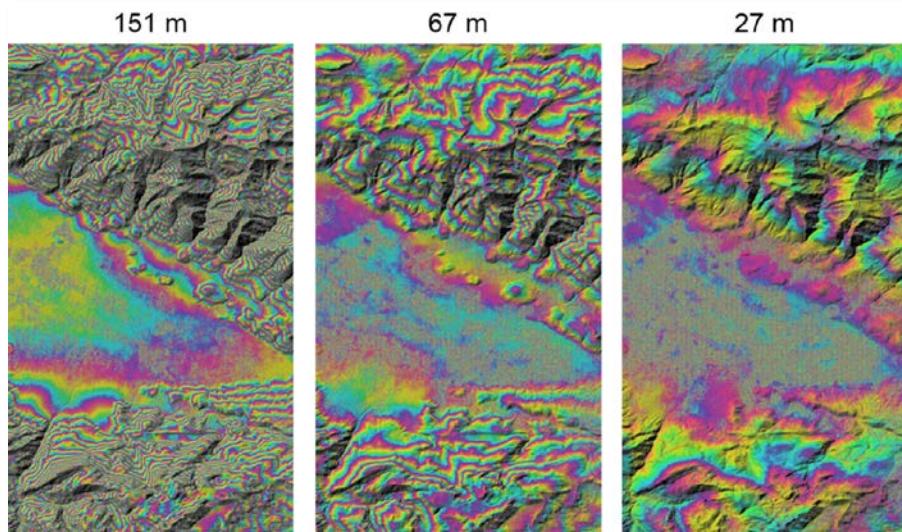


Figure 8: Effect of the perpendicular baseline on the interferogram ([Braun 2021](#))

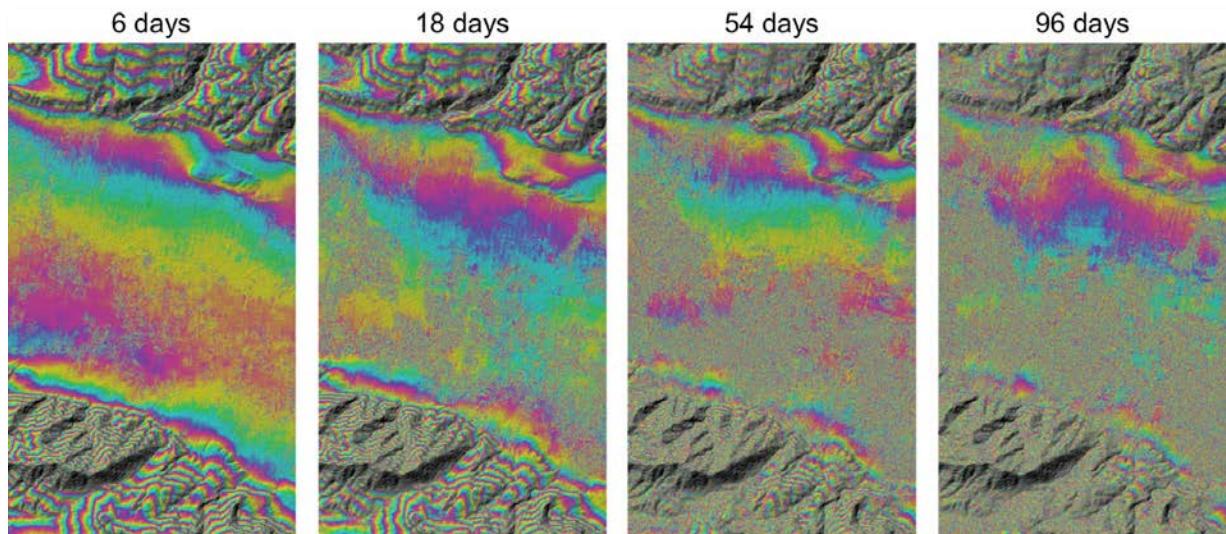


Figure 9: Effect of the temporal baseline on the interferogram ([Braun 2021](#))

To check the baseline information of your image pair, open Radar > Interferometric > InSAR Stack Overview. First, click on “Add Opened” to load the two Sentinel-1 products into the list at the top. Their acquisition date, track and orbit should now be displayed.

Secondly, click “Overview” to load their metadata. The list at the bottom should then show information on

- perpendicular baseline (Bperp) [meters]
- temporal baseline (Btemp) [days]
- the modelled coherence [0-1]
- height ambiguity [meters] how many meters of height difference are represented by one color cycle in the interferogram
- the mean Doppler centroid frequency difference

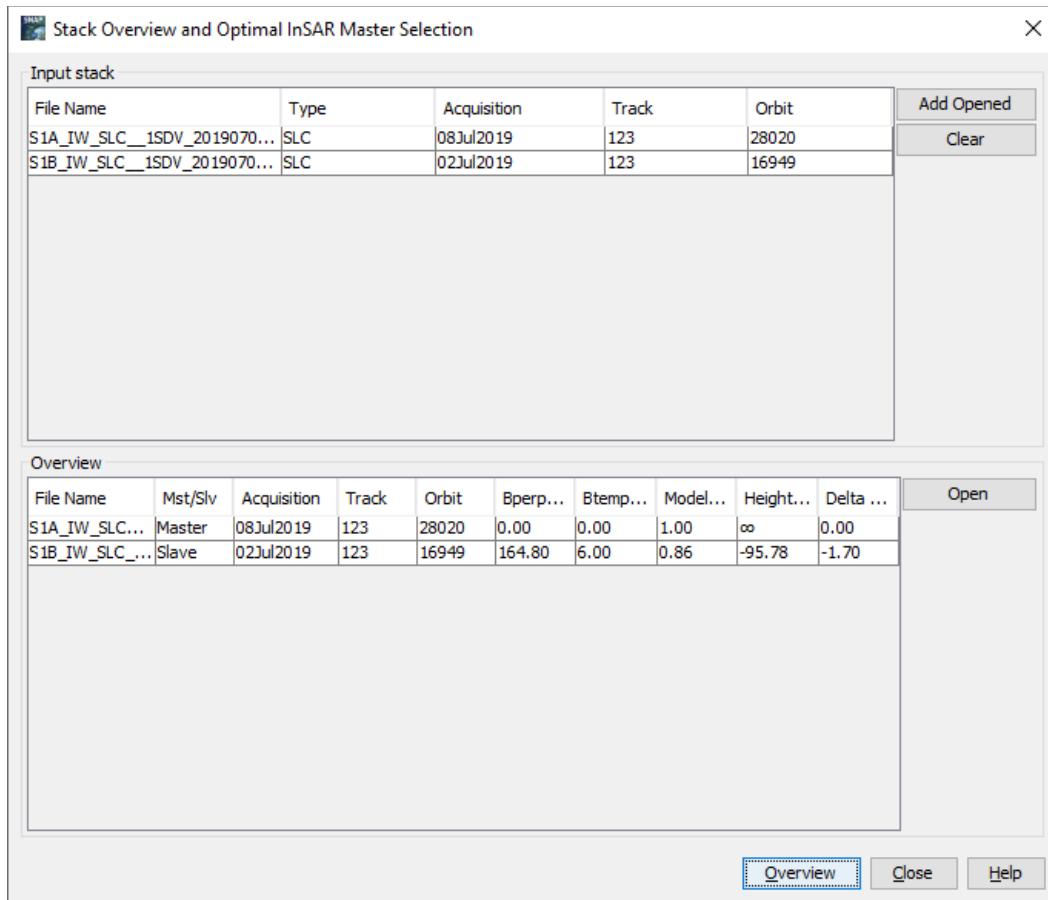


Figure 10: InSAR Stack Overview

Coregistration

To exploit the phase difference of the acquisitions, a stack containing both products must be created first. Coregistration makes use of image statistics to align both products at sub-pixel accuracy. While conventional Stripmap radar products can be coregistered within one step, S1 TOPSAR products require a series of steps, because of their special form of acquisition (Figure 1).

SNAP offers to combine all these steps within the *S-1 TOPS Coregistration with ESD* operator, but this processing chain consumes a lot of memory. In this tutorial, the single steps to correctly coregister the products are performed individually and successively.

TOPS Split

S-1 TOPS Split is applied to the data to select only those bursts which are required for the analysis. They are marked in blue in Figure 1. Currently, each Sub-Swath is processed separately. Note: If the area of interest covers several Sub-Swaths, they have to be merged with the *S-1 TOPS Merge* operator after the Sub-Swaths were debursted.

To reduce the loaded data to the area of interest, open the *S-1 TOPS Split operator* (under *Radar > Sentinel-1 TOPS*) and select sub-swath **IW2** and **VV** polarization in the *Processing Parameters*.

Because the two products are shifted along-track (Figure 7), different bursts have to be selected for each product. Reduce the bursts by dragging the grey triangles towards the middle as defined in the following table:

Input product	Subswath	Polarisation	Bursts	Output name
S1B_IW_SLC_1SDV_20190702...	IW2	VV	3 - 5	S1B_20190702_split
S1A_IW_SLC_1SDV_20190708...	IW2	VV	1 - 3	S1B_20190708_split

Use the preview to check the location of the selected area (Figure 11). Confirm with **Run** and repeat the step for the second S1 image.

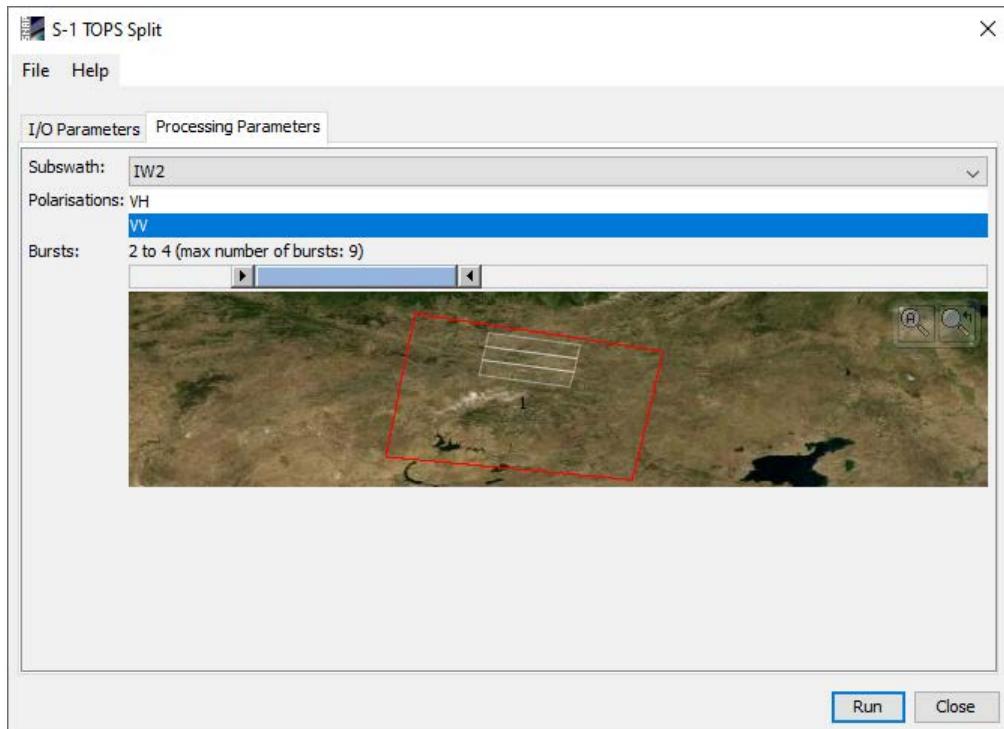


Figure 11: TOPS Split

Applying Orbit Information

Orbit auxiliary data contain information about the position of the satellite during the acquisition of SAR data. They are automatically downloaded for Sentinel-1 products by SNAP and added to its metadata with the *Apply Orbit File* (under the menu point *Radar*) operator.

The Precise Orbit Determination (POD) service for Sentinel-1 provides restituted orbit files and precise Orbit Ephemerides (POE) orbit files. POE files cover ca. 28 hours and contain orbit state vectors at intervals of 10 seconds intervals. Files are generated one file per day and are delivered within 20 days after data acquisition.

If precise orbits are not yet available for your product, restituted orbits can be selected which may not be as accurate as the Precise orbits but will be better than the predicted orbits available within the product.

Execute the operator for both split products as generated in the previous step (Figure 12).

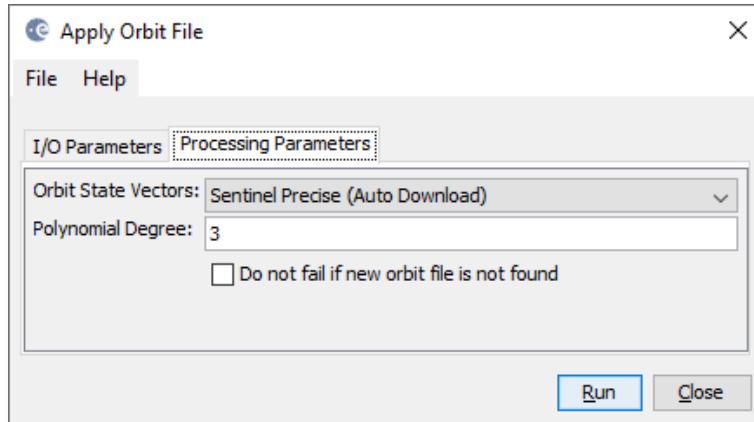


Figure 12: Apply Orbit File

Back Geocoding and Enhanced Spectral Diversity

The S-1 Back Geocoding operator (under *Radar > Coregistration > Sentinel-1 TOPS Coregistration*) coregisters the two split products based on the orbit information added in the previous step and information from a digital elevation model (DEM) which is downloaded by SNAP.

Add the products of the two dates (ending with “_split_Orb”) to the file list in the *ProductSet-Reader* tab and select **SRTM 1Sec HGT (AutoDownload)** in the *Back-Geocoding tab* (Figure 13).

Please be aware that SRTM is only available between 60° North and 54° South. If your area lies outside this coverage (<https://www2.jpl.nasa.gov/srtm/coverage.html>), you can use one of the other DEMs with AutoDownload option or use an external DEM (just make sure it stored as a GeoTiff and projected in geographic coordinates / WGS84).

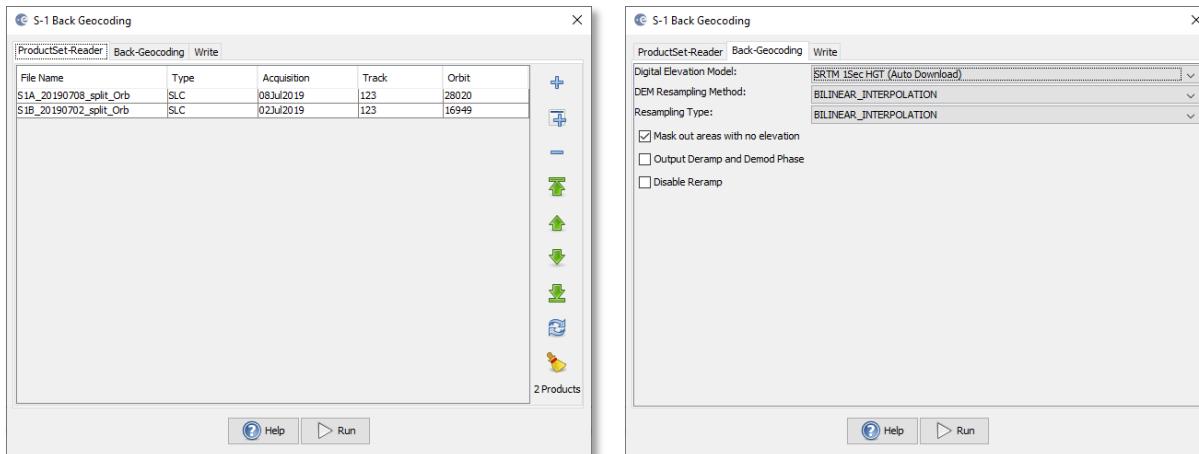


Figure 13: Back Geocoding

To increase the quality of the coregistration you apply the S-1 Enhanced Spectral Diversity (ESD) operator (under *Radar > Coregistration > Sentinel-1 TOPS Coregistration*) on the stack generated by the Back Geocoding. It applies range and azimuth shift corrections to the secondary image.

Note: This operator is only needed when you select more than one burst. If you only selected one burst in the TOPS Split step, you do not need the ESD operator.

After the coregistration is completed, it is advisable to visually check the quality of the stack. This can be done by an RGB representation of the reference and secondary¹ product which shows if the images are correctly aligned. Select the reference for red and green and the secondary image for blue (Figure 14)².

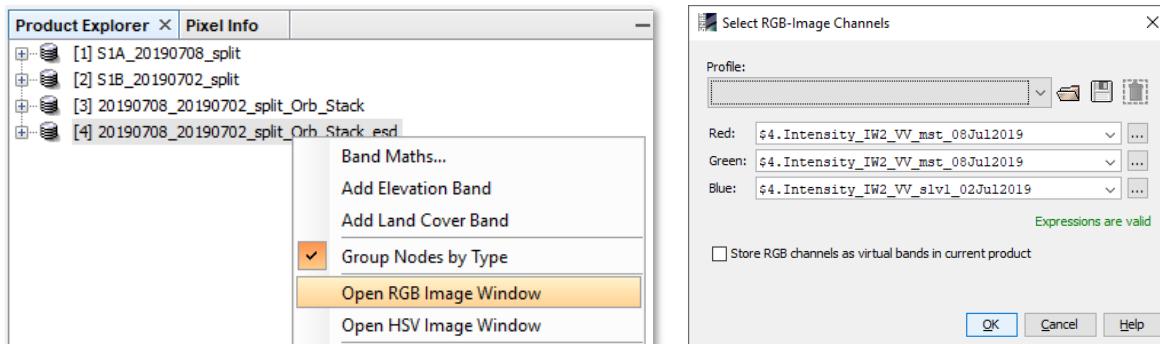


Figure 14: Generation of an RGB image

Zoom in to an area with distinct surfaces, for example the border between land and water. The RGB image should be clear and sharp and not be dominated by one of the images (yellow [red+green] for the reference or blue for the secondary image). The only exception are changes in landcover or scattering mechanisms which occurred in the time between the first and the second image acquisition (Figure 15).

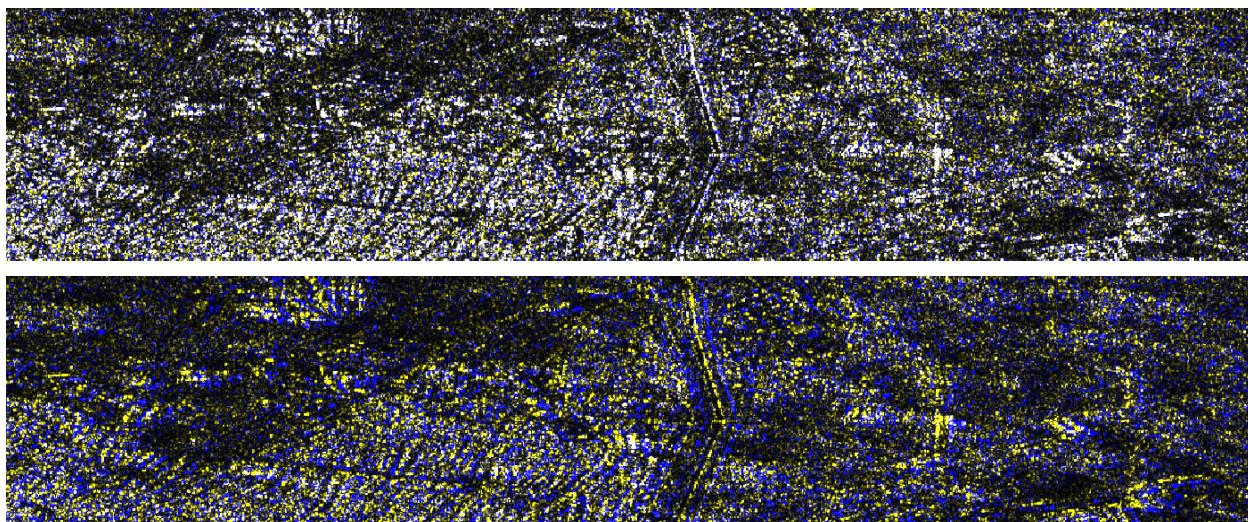


Figure 15: Successful (top) vs. failed (bottom) coregistration in an RGB image

¹ We support the [statement of the executive committees of WInSAR and COMET](#) to exchange the inappropriate terminology in all InSAR-related fields. Accordingly, the former "master/slave" will be replaced by "reference/secondary" in future versions of SNAP.

² <https://www.scientificamerican.com/article/end-of-the-rainbow-new-map-scale-is-more-readable-by-people-who-are-color-blind/>

Interferogram Formation and Coherence Estimation

An interferogram is formed by cross multiplying the reference image with the complex conjugate of the secondary. The amplitude of both images is multiplied while the phase represents the phase difference between the two images.

The interferometric phase of each SAR image pixel would depend only on the difference in the travel paths from each of the two SARs to the considered resolution cell. Accordingly, the computed interferogram contains phase variation

Because of the predominantly short perpendicular baselines and the comparably quick decorrelation of C-band SAR data, repeat-pass interferometry for DEM generation is challenging, especially over vegetated areas. So please be aware that, despite the higher spatial resolution, phase decorrelation will lead to errors and the resulting elevation data is not of better quality than of freely available DEMs, such as [SRTM](#) or [AW3D30](#), in most cases.

Coherence is calculated as a separate raster band and shows how similar each pixel is between the secondary and reference images in a scale from 0 to 1. Areas of high coherence will appear bright. Areas with poor coherence will be dark. In the image, vegetation is shown as having poor coherence and buildings have very high coherence.

To compute the interferogram and the coherence bands, apply the *Interferogram Formation* operator (under *Radar > Interferometric > Products*). Select the coregistered stack you generated in the previous step as an input and make sure to check the boxes:

Subtract flat-earth phase: The flat-earth phase is the phase present in the interferometric signal due to the curvature of the reference surface. The flat-earth phase is estimated using the orbital metadata information and subtracted from the complex interferogram.

Include coherence estimation: This produces a coherence band in the output calculated based on a window of 10x3 pixels in range/azimuth direction based on equation 1.13 in [ESA TM-19C](#).

Please **do not** check "Subtract topographic phase", because this is the information of interest.

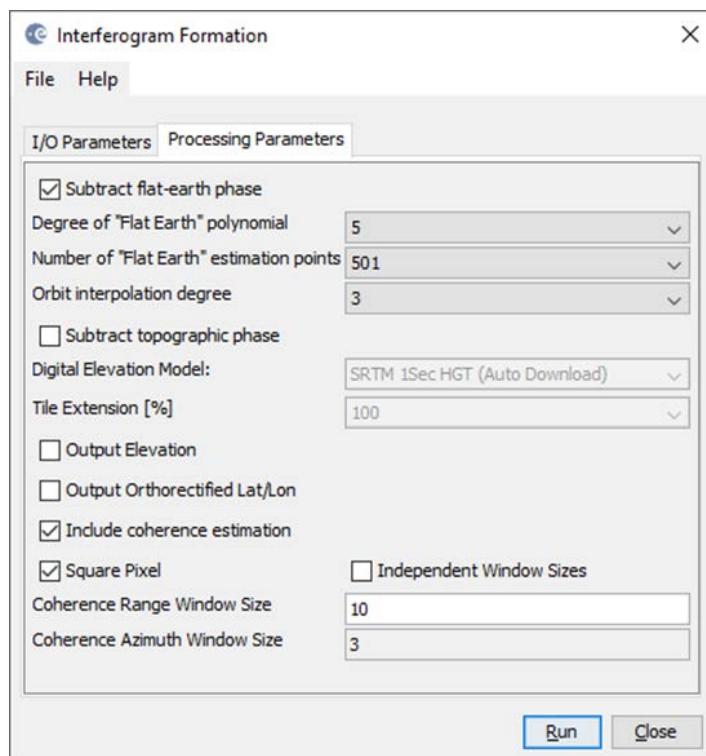


Figure 17: Interferogram Formation

The resulting product will contain the interferogram (`Phase_ifg_IW...`) and the coherence (`coh_IW_...`) as separate bands (Figure 18). Double click them to check for their quality.

The interferogram is displayed in a rainbow color scale ranging from - topography, atmosphere and potential surface deformation (considered zero). The patterns, also called appear in an interferogram as cycles of arbitrary colors, with each cycle representing half the sensor's wavelength.

To derive a DEM of sufficient quality, these fringes must be visible throughout the entire image. Areas of phase decorrelation appear as noise in the interferogram.

The coherence shows the areas where the phase information is coherent, which means that it can be used to measure topography (as in this tutorial) or deformation (includes removing the topographic phase). While large areas show high coherence (above 0.6), river valleys are dark and have low coherence (below 0.3). Accordingly, phase information over low coherence areas will not produce correct elevation measures. If low coherence areas are too dominant in the image, the later unwrapping will fail and produce faulty or random results.

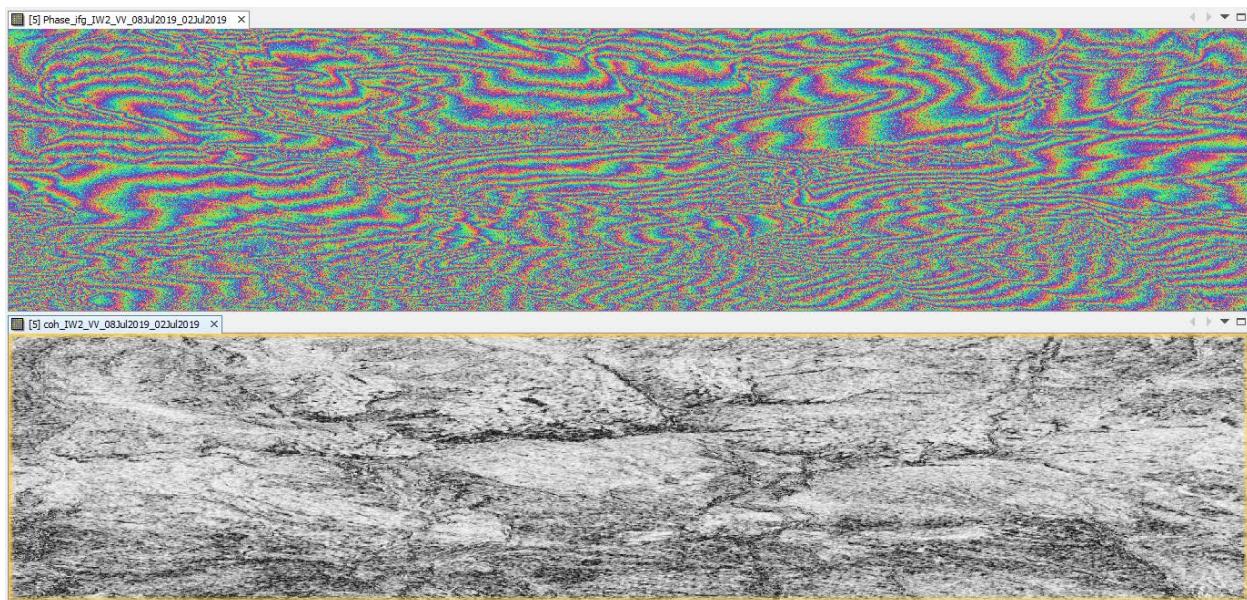


Figure 18: Interferogram (top) and coherence (bottom)

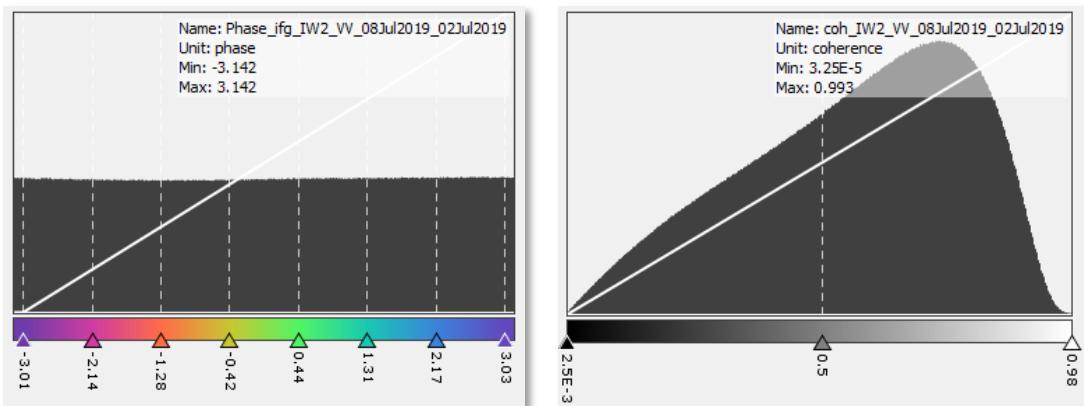


Figure 19: Histogram of interferogram (left) and coherence (right)

TOPS Deburst

To remove the seamlines between the single bursts, the *S-1 TOPS Deburst operator* (under *Radar > Sentinel-1 TOPS*) is applied to the interferogram product. It does not require any user input (Figure 20). The output contains the same bands as the input, but with merged bursts according to their zero Doppler time. More information on this step is provided in the [Sentinel-1 User Guide](#).

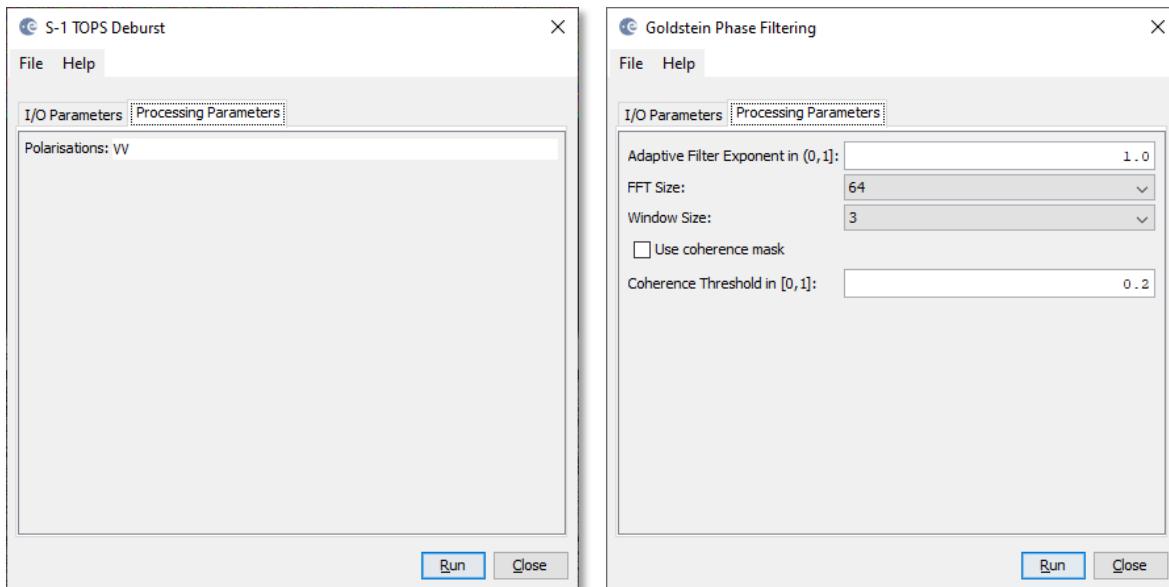


Figure 20: TOPS Deburst (left) and Goldstein phase filtering (right)

Goldstein Phase Filtering

Interferometric phase can be corrupted by noise from temporal and geometric decorrelation, volume scattering, and other processing errors. Phase information in decorrelated areas cannot be restored, but the quality of the fringes existing in the interferogram can be increased by applying specialized phase filters, such as the Goldstein filter which uses a Fast Fourier Transformation (FFT) to enhance the signal-to-noise ratio of the image. This is required for a proper unwrapping in the subsequent step. A detailed description of this filter and its parameters is given in the publication of [Goldstein & Werner \(1998\)](#).

Apply the Goldstein Phase Filtering (under *Radar > Interferometric > Filtering*) to the debursted image. The output is a filtered phase image, the coherence is not affected.

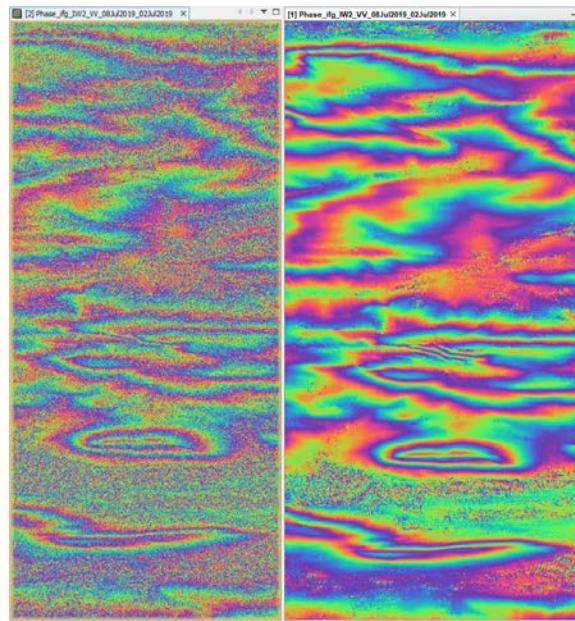


Figure 21: Interferogram before (left) and after (right) Goldstein phase filtering

Create a Subset

During the previous processing steps, empty pixels at the edge of the interferogram might have been introduced, for example in areas which are not covered by both input images. To crop these areas, the *Subset* (under Raster) operator can be used. This not only reduces the size of the processed data in the subsequent steps, but also prevents later unwrapping errors. Select the filtered product, start the *Subset* operator, enter the following pixel coordinates (Figure 22), and confirm with **Run**.

Scene start X: 1000
 Scene start Y: 50
 Scene end X: 25000
 Scene end Y: 2750

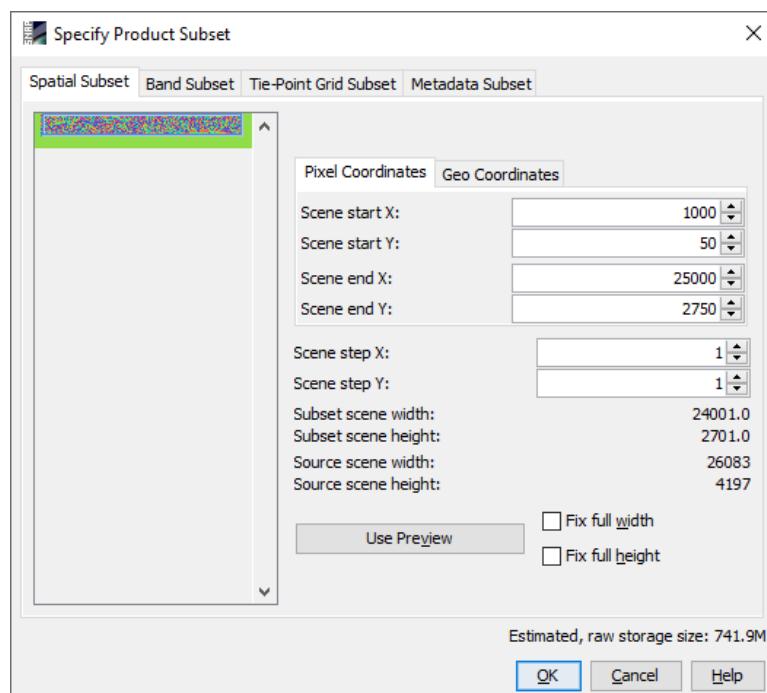


Figure 22: Creating a subset

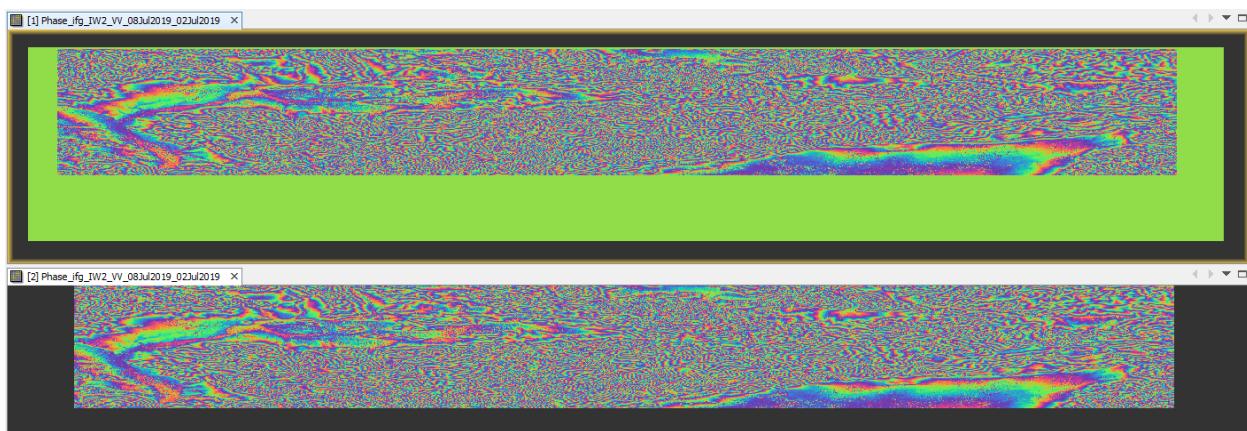


Figure 23: Interferogram before (top) and after (bottom) creating the subset

A new product is shown in the *Product Explorer*, starting with `subset_0_of_` for each subset. These products are only of temporary nature and lost after SNAP is closed. To permanently store them, right-click on the products, select **Save Product As...** and save them in BEAM DIMAP format under the name `20190708_20190702_split_Orb_Stack_esd_ifg_deb_flt_subset`

Phase Unwrapping

In order to relate the interferometric phase to the topographic height, the phase must first be unwrapped. The altitude of ambiguity is defined as the altitude difference that generates an interferometric phase change of 2π .

Phase unwrapping solves this ambiguity by integrating phase difference between neighboring pixels. After deleting the phase variation between two points on the flattened interferogram provides a measurement of the actual altitude variation (Figure 24). Accordingly, unwrapped results should be interpreted as a relative height/displacement between pixels of two images.

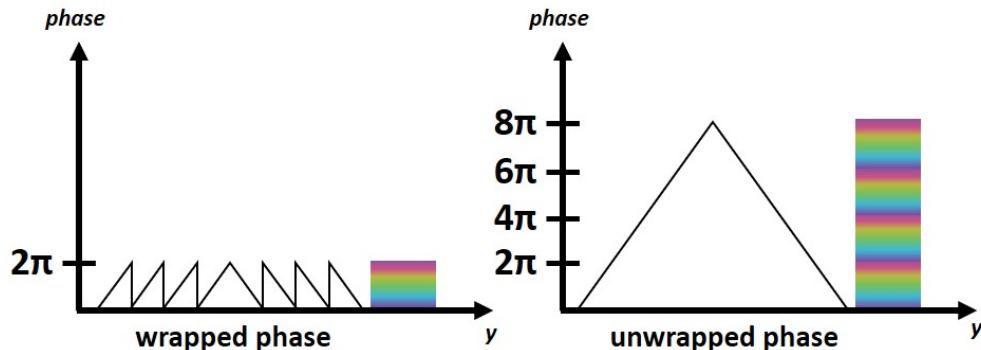


Figure 24: Principle of phase unwrapping

For optimal unwrapping results it is recommended to filter the interferogram as done in the previous step and eventually apply multi-looking (under Raster > SAR Utilities). As the fringe patterns are quite fine scaled (Figure 21), no multi-looking is applied in this case.

The quality and reliability of unwrapped results very much depends on the input coherence. Reliable results can only be expected in areas of high coherence. Although no definite threshold exists, a minimum coherence of 0.3 is suggested.

Unwrapping in SNAP follows three distinct steps:

1. **Export** of the wrapped phase (and definition of the parameters)
2. **Unwrapping** of the phase (performed outside SNAP by snaphu)
3. **Import** of the unwrapped phase back into SNAP

Because snaphu is an independent software (see under the section "Install snaphu" at the beginning of this document), the unwrapping is executed outside SNAP, but the plugin allows to call this execution, so no command line processing is required any longer.

Depending on the capabilities of the system, the unwrapping can take a considerable amount of time. However, snaphu supports multi-threading which means that the computation can be distributed over multiple processor cores. This has to be defined during the export.

Export

The Export operator (under *Radar > Interferometric > Unwrapping*) converts the interferogram (as the wrapped phase) into a format which can be read by snaphu. Furthermore, a couple of parameters can be selected which affect the unwrapping process and stored in a configuration file which is accessed by snaphu.

The source product is the subset created in the previous step. In the *SnaphuExport* tab, select your working directory as the target folder (here: C:\Temp\S1_InSAR_DEM). If the selection of the directory does not work, simply copy and paste the path of your working directory into the text field. Select **TOPO** as *Statistical-cost mode* and select **200** pixels for *Row Overlap* and *Column Overlap*. Depending on the number of processors of your computer, you can also increase the *Number of Processors* variable.

Note: You can neglect the eventual error message (`Error: [NodeId: SnaphuExport Please add a target folder`). It will go away once you switch tabs or hit **Run**, as long as you have entered a valid target folder.

To learn about the meaning and impact of all parameters, please consult the [official documentation](#).

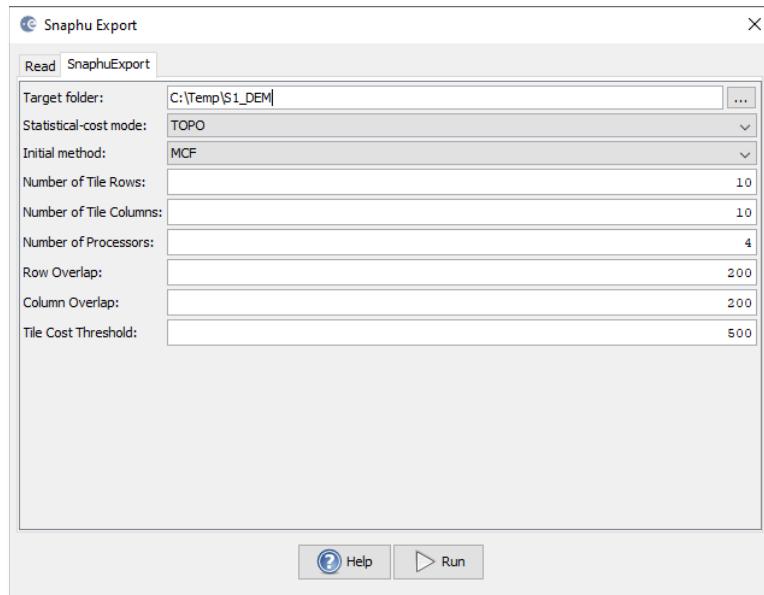


Figure 25: Snaphu export

Hit Run to start the export. A directory is created in your working directory with the same name as the product you selected as an input (here: 20190708_20190702_split_Orb_Stack_esd_ifg_deb_flt_subset). Inside this folder, you find:

- the **coherence**: image (*.img) and metadata (*.hdr)
- the **wrapped phase**: image (*.img) and metadata (*.hdr)
- the **unwrapped phase**: only the metadata (*.hdr), because the image (*.img) is first to be created by snaphu in the next step.
- a **configuration file** (snaphu.conf) containing the parameters defined in the export operator

Unwrapping with snaphu

Once the product is exported correctly, the unwrapping can be started from within SNAP, by calling the *Snaphu-unwrapping* operator (under *Radar > Interferometric > Unwrapping*). As an input product, select the subset which was created before the export from the drop-down menu. For the output folder in the *Processing Parameters* tab you can activate **Display execution output** and select the folder which was created during the export (here: 20190708_20190702_split_Orb_Stack_esd_ifg_deb_ft_subset). To start the unwrapping, click **Run**. SNAP then sends the command stored in snaphu.conf to the snaphu.exe which creates the raster image belonging to the unwrapped phase metadata.

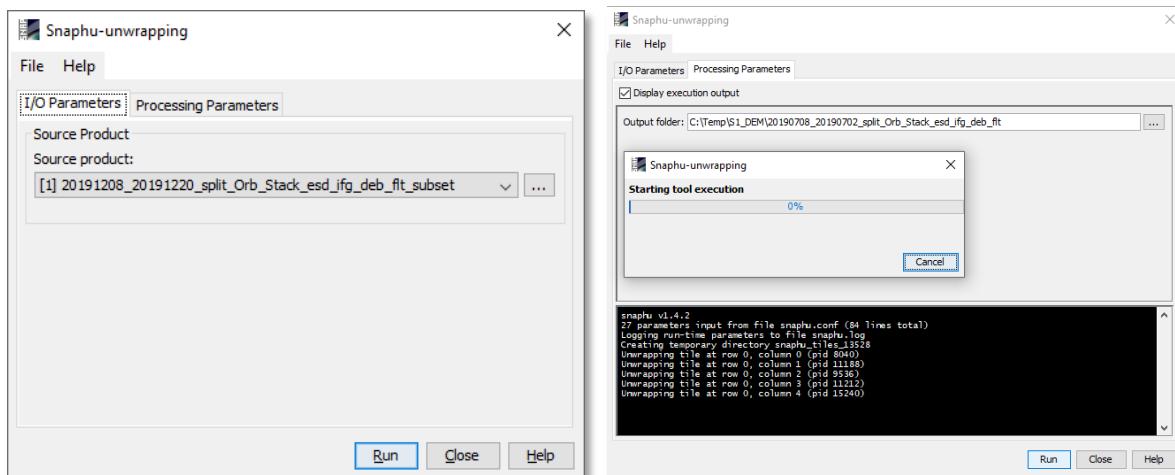


Figure 26: Unwrapping with the snaphu plugin

Note: If the tool is not executed by clicking **Run**, go to *Manage External Tools* in the *Tools* menu. Select “**Snaphu-unwrapping**” and click **Edit the selected operator** to open the configuration and enter the export directory in the variable **USERPROFILE** under the *System Variables* tab. Confirm with **OK** and start the *Snaphu-unwrapping* operator again.

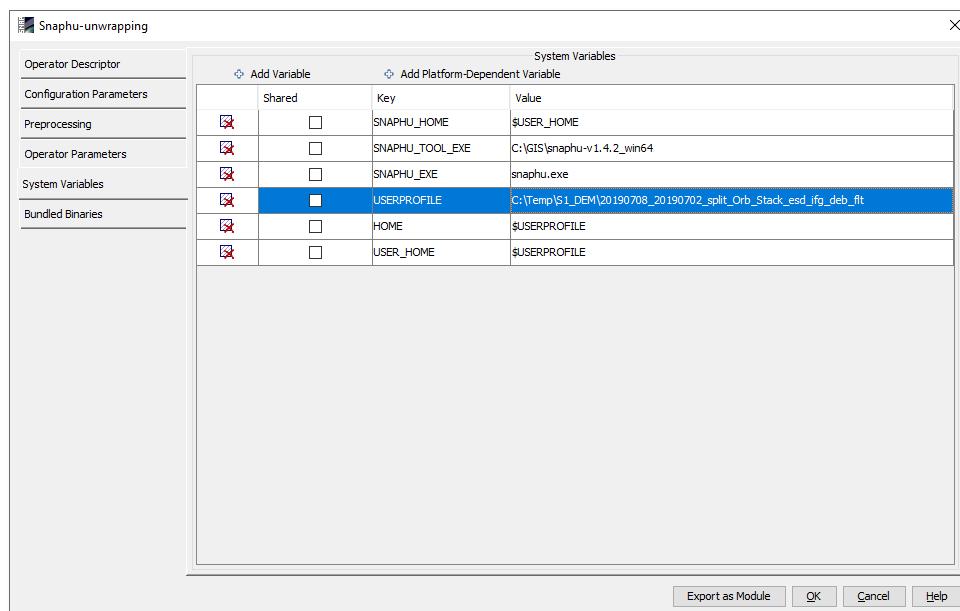


Figure 27: System variables of the snaphu plugin

Note that unwrapping can take a considerable amount of time. To break the raster into smaller chunks, snaphu divides it by standard into 10 rows and 10 columns, leading to a total of 100 tiles to be unwrapped. These tiles are merged afterwards based on the selected pixel overlap (here 200 pixels). A progress bar will inform you about the remaining time. The calculation is completed when the progress reaches 100% and the output states "Finished tool execution in ... seconds". You can then close the operator.

Alternative option: If the unwrapping does not work with the plugin from within SNAP, snaphu can also be started from the command line. It can be downloaded from the following page which also contains instruction for its manual execution: <https://step.esa.int/main/third-party-plugins-2/snaphu/>

Import

The opened unwrapped phase does not have any metadata or geocoding. The *Snaphu import* (under *Radar > Interferometric > Unwrapping*) converts the it back into the BEAM DIMAP format and adds the required metadata from on the wrapped phase product as they have the same geometry. The Snaphu import needs the following tabs:

1-Read-Phase: Here, you select the subset of the interferogram (before the export) from the drop-down menu.

2-Read-Unwrapped-Phase: Select the  icon to open a file menu and navigate to the export directory. Select the *.hdr file of the unwrapped phase (here `UnwPhase_ifg_[...].hdr`). Note: The error message will then vanish if you proceed to the next tab.

3-SnaphuImport: Leave the option "Do NOT save Wrapped interferogram in the target product" unchecked, because it is required in the later step.

4-Write: To store the imported unwrapped band in a separate product (recommended), add '`_unw`' to the output name (here: `20190708_20190702_split_Orb_Stack_esd_ifg_deb_flt_subset_`) and click **Run**.

A new product is added to the Product Explorer which contains the wrapped interferogram (`Phase_ifg_IW...`), the coherence (`coh_IW...`) and the unwrapped phase generated with snaphu (here: `UnwPhase_ifg_IW2_VV_08Jul2019_02Jul2019`)

Double click on the unwrapped phase to see if the unwrapping was successful. It should be a smooth raster with little variation except for the areas of expected deformation (Figure 28). All fringe patterns are summarized to absolute changes (Figure 24). Unwrapping errors can occur in areas of low coherence and in urban areas with many vertical objects.

If you notice strange grid-like patterns in your unwrapped results, you can change the amount of tile columns and rows in the export (or directly in the `snaphu.conf` file) and run the unwrapping again. Just make sure you delete the unwrapped phase (`UnwPhase_ifg_[...].img`) and the temporary files in the export directory before you restart the unwrapping. Sometimes it is also favorable to switch the statistical cost-mode from **DEFO** to **SMOOTH** or the initial method from **MCF** to **MST** and compare the outputs.

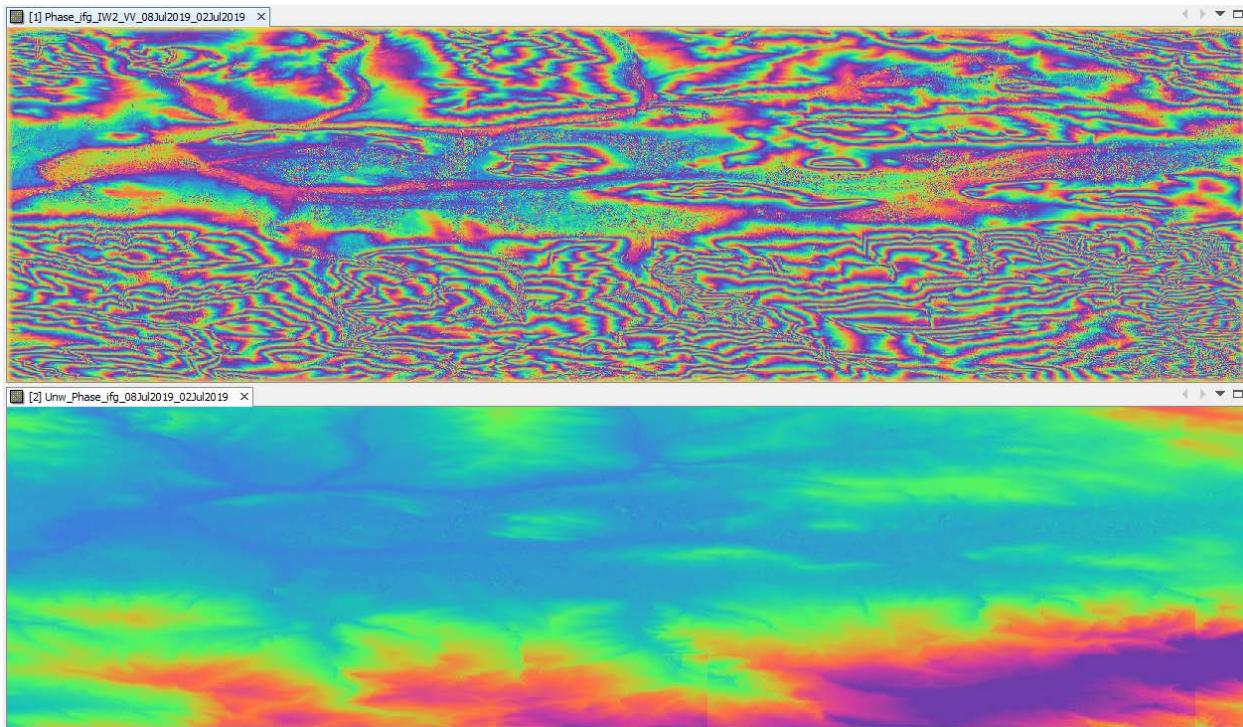


Figure 28: Phase before (top) and after (bottom) unwrapping

Phase to Elevation

The unwrapped phase is now a continuous raster but not yet a metric measure. To convert the radian units into absolute heights, the *Phase to Elevation* operator (under *Radar > Interferometric > Products*) is applied. It translates the phase into surface elevations along the line-of-sight (LOS) in meters. The LOS is the line between the sensor and a pixel. A DEM is used to put the elevation values in the correct level.

In the *Processing Parameters* tab, select **SRTM 1Sec HGT (AutoDownload)** as input DEM.

The operator is applied to the unwrapped phase which was imported in the last step. It produces an output which looks similar to the unwrapped phase (slightly different predefined color ramp), but now each pixel has a metric value indicating its height above sea level.

You can plot a *Histogram* to check the frequency distribution of the values (Figure 30).

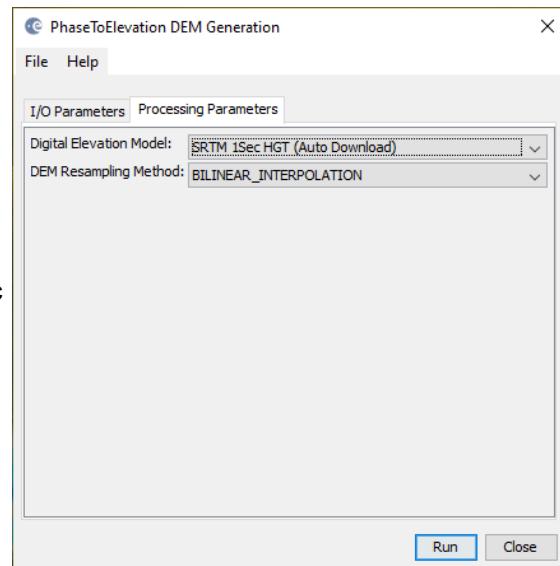


Figure 29: Phase to Elevation

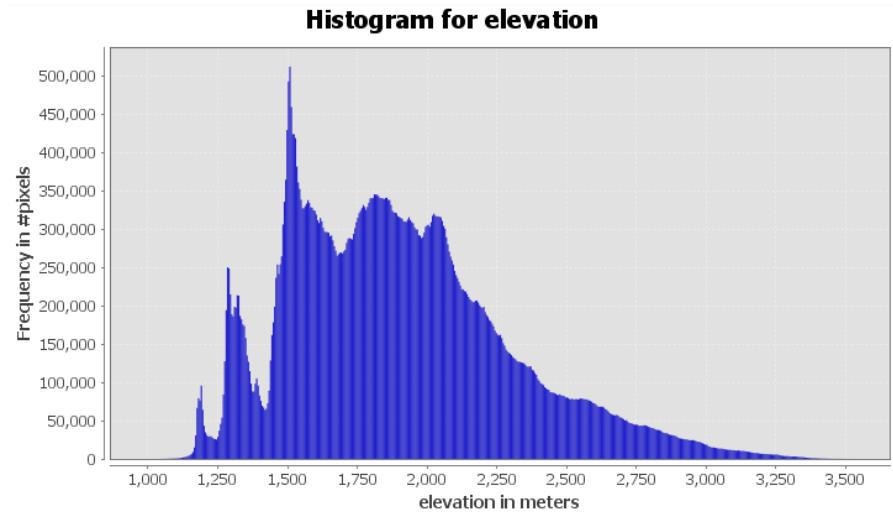


Figure 30: Histogram of the elevation raster

Note: The original phase and coherence bands are not automatically copied into the resulting raster of the *Phase to Elevation* operator. If they are needed in the final product, they can be added via the *Band Maths* operator (right-click on the elevation product and select **Band Maths**).

Call the new raster which is to be generated coherence and uncheck the “Virtual” option (Figure 31, left). Open the *Band Maths Expression Editor* by clicking **Edit Expression**. You can now switch between products which have the same dimensions (rows and columns) in the Band Maths Expression Editor and double-clicking the coherence band of a previous product to add it to the expression window (Figure 31, right). Confirm with **OK** (twice) to apply the calculation.

The coherence band is now part of the elevation product. Save it by selecting *File > Save Product* in the menu.

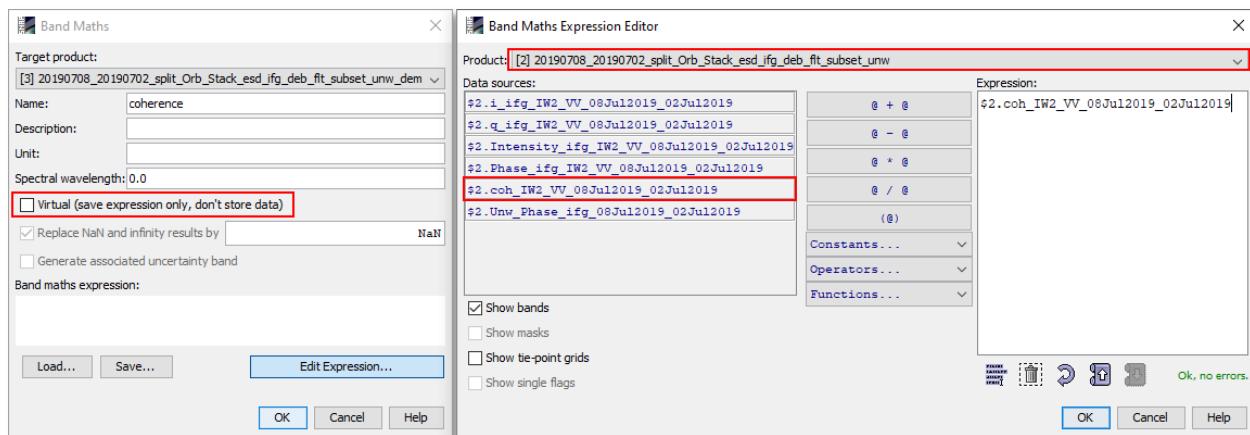


Figure 31: Transfer of bands between products

You can digitize a line and use the *Profile Plot* tool  to visualize single elevation patterns and their value ranges (Figure 32). This is also a good way to check also the amount of noise in the lower coherence areas. Smooth lines indicate good results while sawtooth patterns are often caused by phase decorrelation.

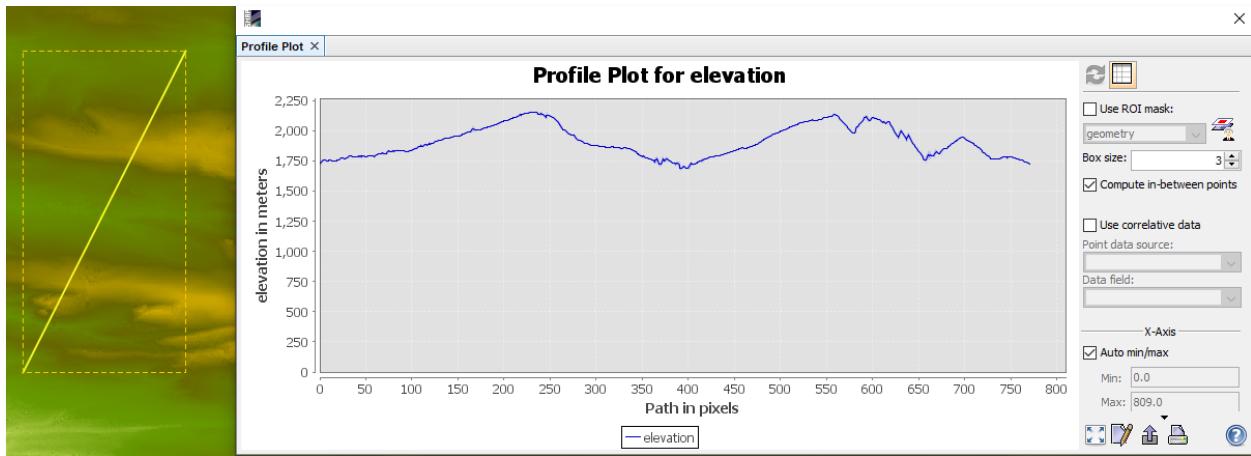


Figure 32: Profile plot the created elevation

Terrain Correction

Terrain Correction will geocode the image by correcting SAR geometric distortions using a digital elevation model (DEM) and producing a map projected product.

Geocoding converts an image from slant range or ground range geometry into a map coordinate system. Terrain geocoding involves using a Digital Elevation Model (DEM) to correct for inherent geometric distortions, such as foreshortening, layover and shadow (Figure 33). More information on these effects is given in the [ESA radar course materials](#).

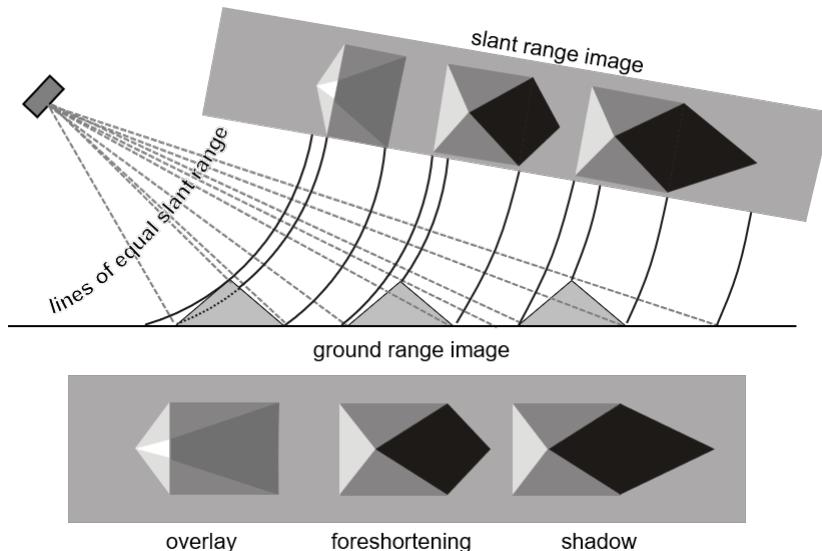


Figure 33: Geometric distortions in radar images ([Braun 2019](#))

Open the *Range Doppler Terrain Correction* operator (under *Radar> Geometric > Terrain Correction*). Select the elevation product as an input in the first tab.

In the Processing Parameters tab, select **SRTM 1Sec HGT (AutoDownload)** as input DEM.

If you want to export the data as a KMZ file to view it in Google Earth **WGS84** must be selected as Map Projection. It is based on geographic coordinates (latitude and longitude). For the later use in a geographic information system (GIS) a metric map projection, such as UTM (Automatic) could be selected as well.

If no **Source Band** is selected, all bands of the input product are geometrically corrected.

If you want to compare the quality of the InSAR DEM, you can select **DEM** as a further output. This writes the SRTM data used for Terrain Correction to a separate elevation band. The Sentinel-1 DEM will then be named `elevation_VV` and the SRTM data is named `elevation`. This option is, however, just for comparison and not mandatory.

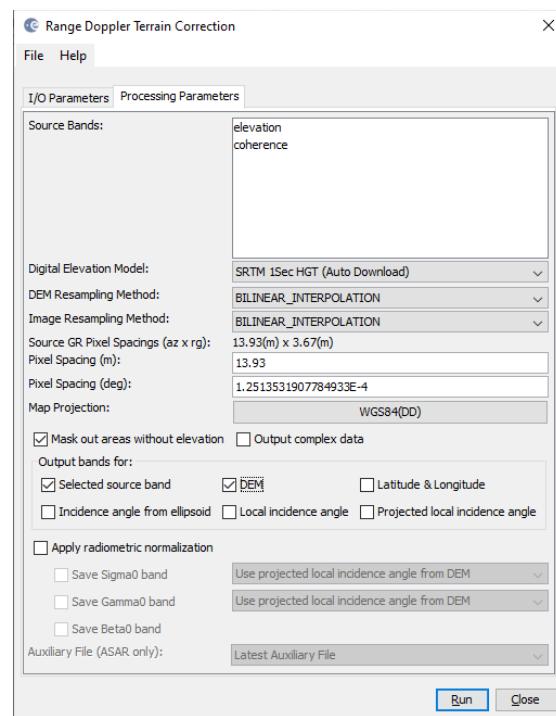


Figure 34: Range Doppler Terrain Correction

Click on **Run** to start the terrain correction. SNAP now establishes a connection to an external elevation database to download all SRTM tiles required to fully cover the input dataset.

Double click on the output to view the geocoded elevation raster (Figure 35).

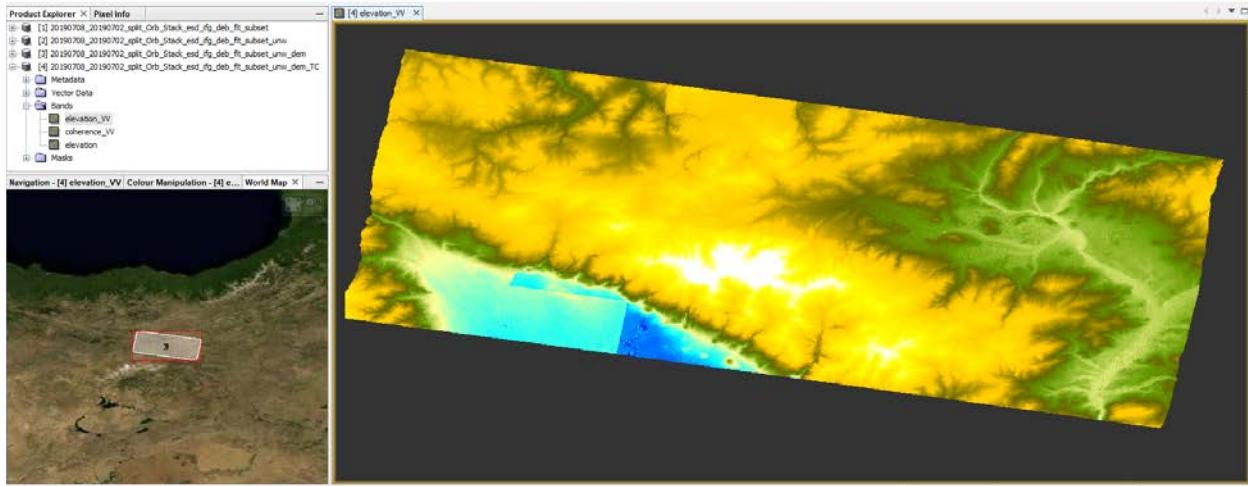


Figure 35: Terrain corrected and geocoded elevation raster

Export to Google Earth

All geocoded products (projected to WGS84) can be exported as a KMZ file to view them in [Google Earth](#).

Select a suitable color scale and color ramp in the *Color Manipulation* tab and then chose *File > Export > Other > View As Google Earth KMZ*

Select an output directory and a suitable filename and confirm with **Safe**. Open the kmz file in Google Earth to view the location of the elevation patterns on the satellite image base map (Figure 36).

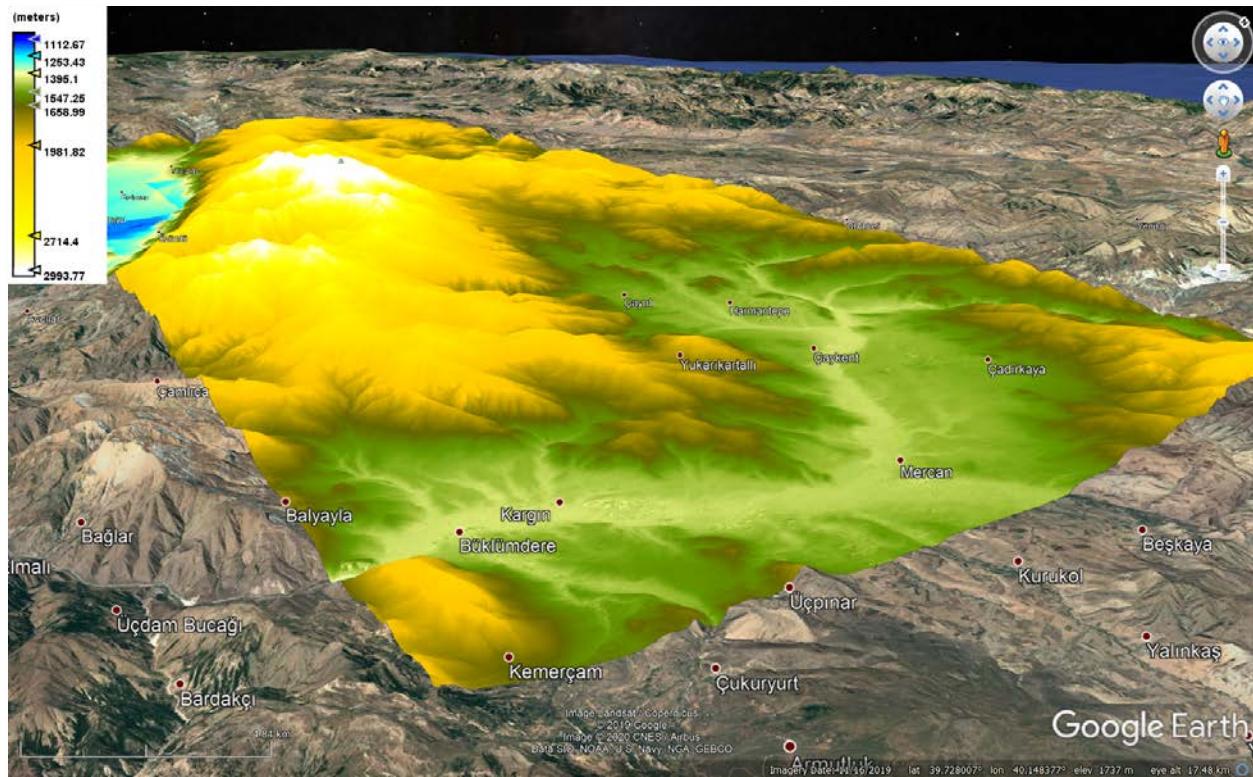


Figure 36: Result exported to Google Earth

Comparison with SRTM

Open the file `elevation_VV.img` (inside the `_TC.data` folder) into a GIS (e.g. [QGIS](#)) and compute a hillshade representation. You might need to set the z-value to 0.000015 (because data projected in WGS84 is based on degrees and the height is given in meters). The coherence layer will give you an indication on where your data is of good quality and where there can be phase errors: This is mainly mainly within agricultural and urban areas, as well as at slopes in the radar shadow (facing southeast).

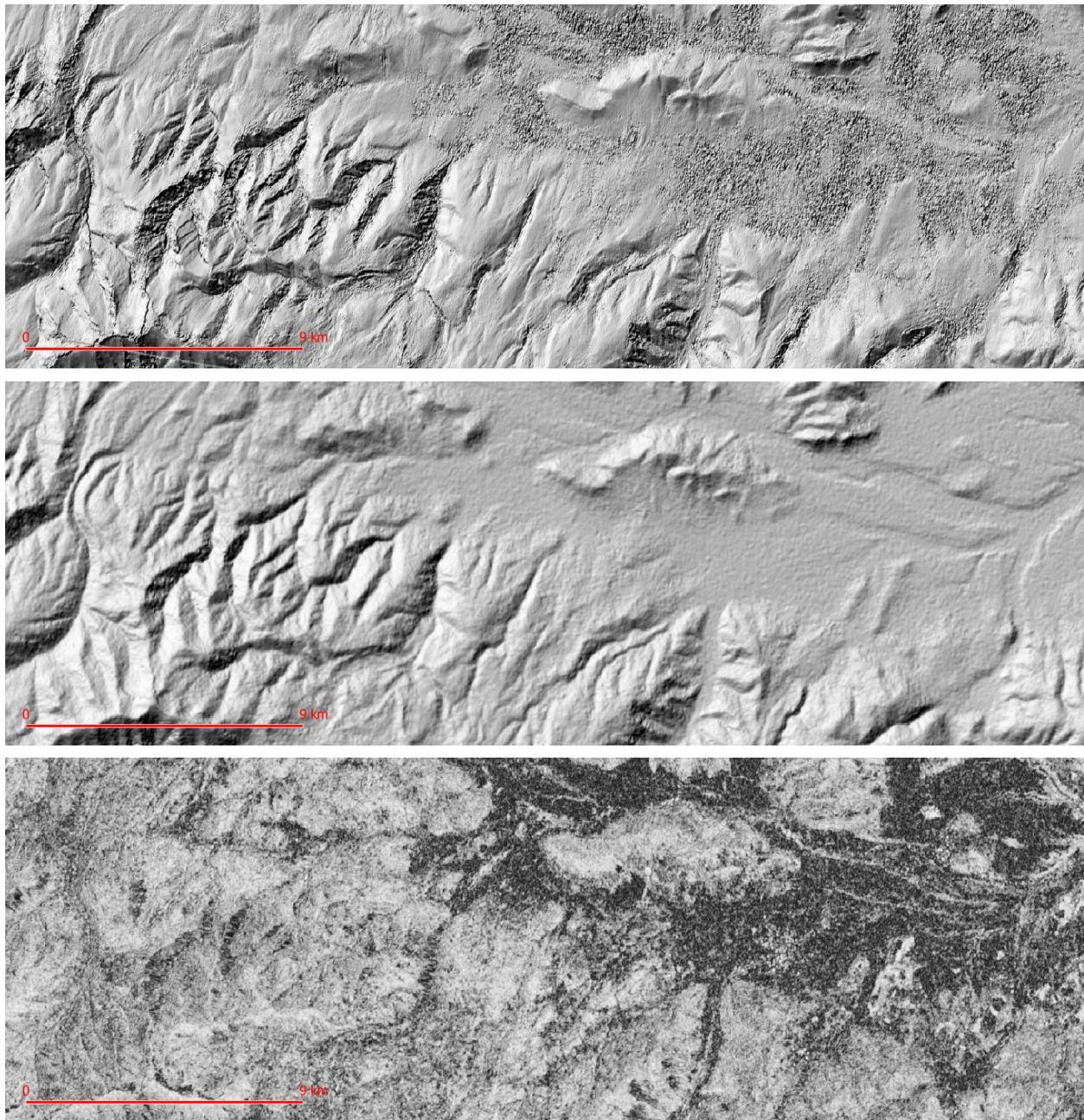
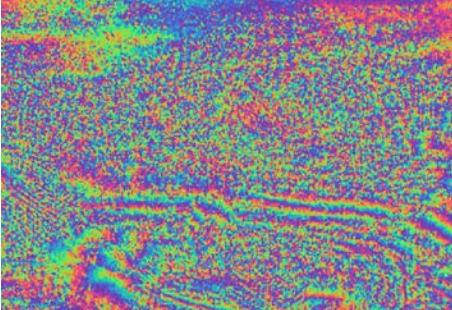
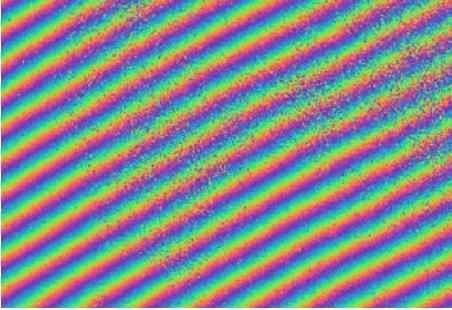
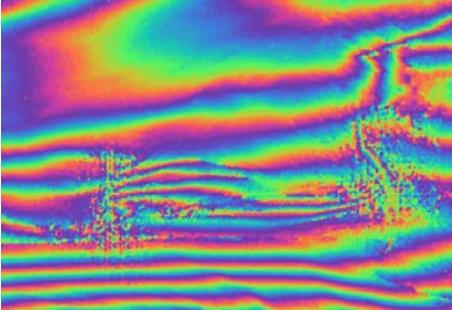
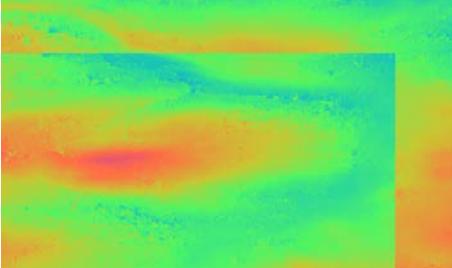
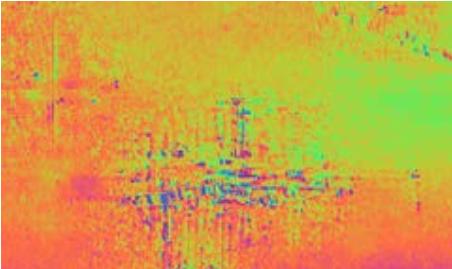


Figure 37: Hillshade of S1 DEM (top) and SRTM (middle); and coherence (bottom)

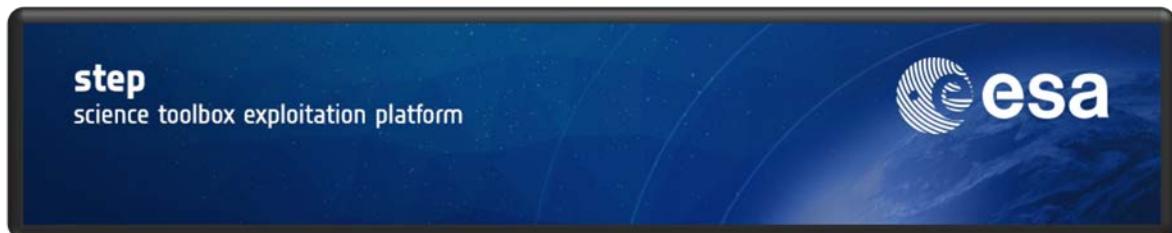
Troubleshooting

Problem	Example	Explanation / Solution
The interferogram looks bad. No fringes are visible		Decorrelation of the phase, probably because of surface changes between both acquisitions (vegetation cover). Things to try: Search image pairs <ul style="list-style-type: none"> • with a shorter temporal baseline • from the dry season • with a larger perpendicular baseline (above 150) Please also see the hints in section "Selection of suitable images"
A trend (ramp) superimposes the topographic fringes		The estimation of the flat-earth phase was not correct. Things to try (in the Interferogram Generation step): <ul style="list-style-type: none"> • increase the Degree of flat-earth polynomial • increase the Number of flat-earth estimation points • increase the Orbit interpolation degree
Strange phase jumps in the interferogram		Some slopes might be too steep for the given wavelength. Things to try: <ul style="list-style-type: none"> • Use images of a different flight direction: ascending instead of descending (or vice versa) • Use images with a larger perpendicular baseline. Please also see the hints in section "Selection of suitable images"
The interferogram contains straight lines with phase jumps		During the unwrapping, the total raster is divided into smaller parts (tiles), by standard 10x10. They are merged in the end. If this fails, such lines appear: Things to try: Repeat the unwrapping <ul style="list-style-type: none"> • with a smaller number of tiles • with larger tile overlap • with SMOOTH instead of TOPO • with MST instead of MCF
The Goldstein phase filter introduces cross-like patterns (often over urban areas)		If the moving window is dominated by a single bright pixel, the FFT of the Goldstein phase filter is blurred by sidelobes which cause these patterns. Things to try: <ul style="list-style-type: none"> • Reduce the Adaptive Filter Exponent to 0.3 or lower.



For more tutorials visit the Sentinel Toolboxes website

<http://step.esa.int/main/doc/tutorials/>



Send comments to the SNAP Forum

<http://forum.step.esa.int/>